SCIENTIFIC NOTE

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Pattern of gastropod shell occupations by *Clibanarius vittatus* (Bosc, 1802): A case study on the Amazon coast

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ABSTRACT

Hermit crabs are cosmopolitan anomuran decapods, which occupy especially gastropod mollusk shells. Their shell occupancy pattern has been described in several regions worldwide, yet it is still poorly studied in the Amazon coast. The aim of this paper was to study the pattern of gastropod shell occupations by hermit crab *Clibanarius vittatus* (Bosc, 1802) according to their sex. Crab and shell morphometric measures were taken, crab sex was determined for comparative analyses of shell occupancy. Samplings were conducted on *Ajuruteua* Beach, *Bragança*, *Pará*, in March and October 2015. A total of 729 hermit crabs of the *Clibanarius vittatus* species were found in seven gastropod shells: *Stramonita haemastoma, S. trinitatensis, Coralliophila caribaea, S. mariae, Latiaxis mansfieldi, Natica lívida*, and *N. marochiensis*. Male were the largest, followed by ovigerous females and intersexed individuals, and occupied the largest shells. Rainy season seems to affect hermit crab reproduction in the northeastern region of the state of *Pará*. Regardless of sex, hermit crabs showed preference for using shells of the species *S. haemastoma* (53.22%) and *S. trinitatensis* (43.07%). These shells, in addition to the high local availability, have attributes that benefit *C. vittatus* reproduction and survival. Furthermore, males seem to select larger shells because they adjust to a larger body size and ovigerous females select them for egg protection.

Keywords: *Caeté* estuary; conch; metabiosis; hermit crab; proto-cooperation.

Padrões de ocupações de conchas de gastrópodes por *Clibanarius vittatus* (Bosc, 1802): Um estudo de caso na costa amazônica

RESUMO

Os caranguejos eremitas são decápodes, anomuros cosmopolitas, que ocupam especialmente as conchas de moluscos gastrópodes. Seu padrão de ocupação de conchas foi descrito em várias regiões do mundo, mas ainda é pouco estudado na costa amazônica. O objetivo deste artigo foi estudar o padrão de ocupação das conchas de gastrópodes pelo caranguejo eremita *Clibanarius vittatus* (Bosc, 1802) de acordo com o sexo. Foram tomadas medidas morfométricas do caranguejo e da concha, o sexo do caranguejo foi determinado para análises comparativas da ocupação da concha. As coletas foram realizadas na Praia de Ajuruteua, Bragança, Pará, em março e outubro de 2015. Um total de 729 caranguejos eremitas da espécie *Clibanarius vittatus* foram encontrados em sete conchas de gastrópodes: *Stramonita haemastoma*, *S. trinitatensis*, *Coralliophila caribaea*, *S. mariae*, *Latiaxis mansfieldi*, *Natica lívida* e *N. marochiensis*. Os machos eram os maiores, seguidos por fêmeas ovígeras e indivíduos intersexuais, e ocupavam as maiores conchas. A estação chuvosa parece afetar a reprodução do caranguejo eremita na região nordeste do estado do Pará. Independentemente do sexo, os caranguejos eremitas mostraram preferência pelo uso de conchas das espécies *S. haemastoma* (53,22%) e *S. trinitatensis* (43,07%). Essas conchas, além da alta disponibilidade local, possuem atributos que beneficiam a reprodução e sobrevivência de *C. vittatus*. Além disso, os machos parecem selecionar conchas maiores porque se ajustam a um tamanho corporal maior e as fêmeas ovígeras as selecionam para proteção dos ovos.

Palavras-chave: Estuário do rio Caeté, concha, metabiose, caranguejo eremita, proto-cooperação.

Introduction

Among Decapoda, species belonging to the order Anomura are known as hermit crabs (BATISTA-LEITE et al., 2005). They have a non-calcified abdominal region (MESCE, 1982), and therefore, most species protect their abdomen occupying empty shells of gastropod species (NEGREIROS-FRANSOZO et al., 1991) in an ecological relationship called metabiosis. In the unique survey of species of hermit crabs done for the Amazon coast, Rieger (1997) describes the major species found in the coastline of *Pará* state belongs to families: Paguridae: *Pylopagurus discoidalis* (A. Milne Edwards, 1880), *Iridopagurus violaceus* (Saint Laurent, 1966) and family Diogenidae: *Dardanus venosus* (H. Milne Edwards, 1848), *D. fucosus* (Biffar; Provenzano, 1972), *C. foresti* (Holthuis, 1959), and *C. vittatus* (Bosc, 1802). However other species are cited in later works on the ecology of hermit crabs such as *C. symmetricus* (RODRIGUES et al., 2016; RODRIGUES et al., 2019; DANIN et al., 2020).

C. vitattus occurs from Virginia (USA) to *Santa Catarina*, in the south of Brazil, and in the present study, they were captured in the upper intertidal zones (MELO, 1999). A study conducted in the coast of the Gulf of *Mexico* indicates that this species becomes resistant to changes in temperature, salinity, and water level (FOTHERINGHAM, 1975), such as the ones that usually occur in northeastern *Pará* state (KOCH; WOLFF, 2002; DIELE; SIMITH, 2006). This allows species to occupy the upper intertidal zones, down to 22 meters depth (MELO, 1999).

Regarding shell utilization, some hermit crab species are opportunistic whereas others consider internal volume, weight, or aperture size (KELLOGG, 1977; BERTNESS, 1980). The association between hermit crabs and shells is important for the survival and reproduction of the former (BORJESSON; SZELISTOWSKI, 1989; GHERARDI, 1990). Other studies on the population structure and occupation of shells by hermit crabs have already been developed by some authors on the Brazilian coast: Ayres-Peres et al. (2008) on the coast of *Rio Grande/RS*, Negreiros-Fransozo et al. (1991), Mantellato e Garcia (2000) on the *São Paulo* coast, Batista-Leite et al. (2005) on the northern coast of the state of *Alagoas*. In the state of *Pará*, Rodrigues e Martinelli-Lemos (2016) analyzed the popu-

lation structure and occupation of gastropod shells by *C. symmetricus* hermit crabs on a sandy beach (*Marapanim*, *Pará*) in northeastern *Pará* state.

Therefore, this study analyzed the population structure of hermit crabs between sexes and if there are differences in gastropod shell utilization on a sandy beach in northeastern Pará state.

Materials and Methods

Ajuruteua beach-PA is located in the *Bragança* peninsula (46°50' and 46°30' W / 0°45' and 1°07' S), 300 km southeast of the Amazon river delta and approximately 200 km from the capital *Belém* (KRAUSE, 2001). The region has well-defined climatic seasons: rainy season between January and May (25.1°C and 3000 mm) and dry season from June to December (30.9°C and 2500 mm) (MORAES et al., 2005). Samplings were conducted in March and October 2015 (rainy and dry seasons, respectively), during low tide in two tidal channels on *Ajuruteua* beach: Farol channel (C1) and Barca channel (C2) (Fig. 1). During rainy season, *Ajuruteua* beach is under a higher influence from *Caeté* river, with a higher flow in this period due to the rains (SOUZA-FILHO, 2009). A visual search was carried out at each site by four researchers during the low tide for 1 hour in area on the beach recently colonized with growing mangrove banks (*Avicennia* sp.). This method was carried out due to its simplicity since compared to other methods such as the use of baits, which have similar results in the capture in terms of abundance species composition (GILCHRIST; ABELE, 1984). The organisms collected were packaged in labelled plastic bags.

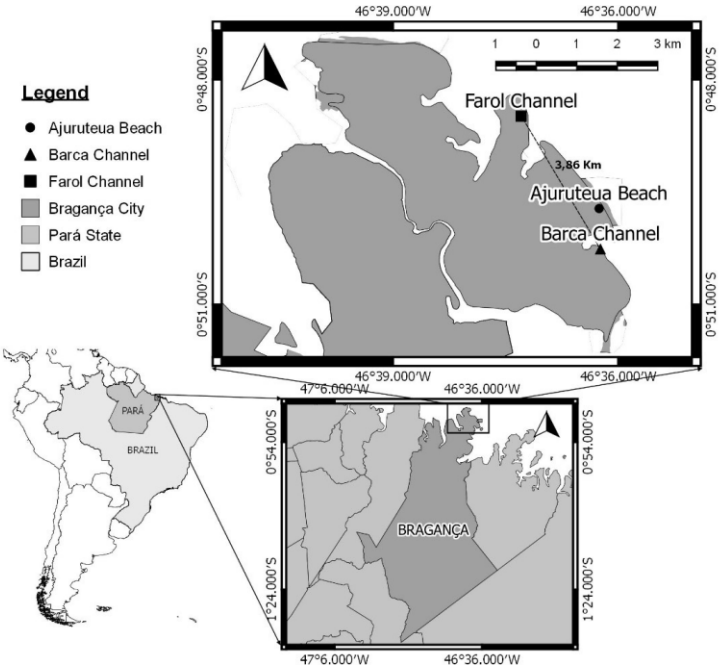

Figure 1. Map of the area sampled. *Ajuruteua* beach-PA showing the two channels whre the collect was carry out: Farol Channel and Barca Channel: (Font: authors, 26/02/2020).

In the laboratory, hermit crabs were extracted from the shell apex using pliers and heat. They were counted, identified to the lowest possible taxonomic level, and sex was determined by the position of gonopores (female – 3rd pair of pereiopods; males – 5th pair of pereiopods, and intersex individuals – 3rd and 5th pair of pereiopods). Morphometric variables were measured using a Zaas digital caliper (200mm/8", Leit. 0,01mm): hermit crabs: cephalothoracic shield length and width (CSL and CSW, respectively); shells: aperture length and width (SAL and SAW, respectively), shell curve width (SCW) and total length (TL).

Sex ratio was estimated as the quotient between the frequency of each sex category and the total number of individuals in the samples. The preference for shells of gastropod species was estimated by the percentage of occupation of hermit crab species, and the Chi-square (X^2) test at 5% significance level (ATKINSON; NEVILL, 1998) was performed to compare occupancy rates of shells among sex and seasons using Biostat software (version 5.0) (AYRES, 2007).

A one-way analysis of variance (ANOVA) was used to test for significant differences in morphometric variables among sex and seasons. All values are expressed as mean ± standard deviation. In order to test the assumption of homogeneity of variances, Cochran's C tests were applied and where necessary, data were log(x+1) transformed. *Tukey's* multiple comparison tests were used when significant differences were detected ($p<0.05$) (SOKAL, 1969).

Results

A total of 729 hermit crabs of the species *C. vittatus* (Bosc, 1802) were collected using shells of seven gastropod species: *Stramonita haemastoma* (Linnaeus, 1767), *S. trinitatensis* (Guppy, 1869), *Coralliophila caribaea* (Abbott, 1958), *S. mariae* (Morretes, 1954), *Latiaxis mansfieldi* (McGinty, 1940), *Natica lívida* (Pfeiffer, 1840), and *N. marochiensis* (Gmelin, 1791), with a preference of 53.22% for *S. haemastoma* shells and of 43.07% for *S. trinitatensis* shells.

Paguran males were the largest, followed by ovigerous females and intersex individuals (CSL – F= 18.25; p= 0.00, CSW – F= 17.02; p= 0.00). Females had the smallest measurements. There were significant differences in all shell measurements according to the sex of hermit crabs (SAL – F= 8.25; p= 0.00, SAW – F= 10.04; p= 0.00, SCW – F= 14.50; p= 0.00, TL – F= 15.02; p= 0.00). Ovigerous females occupied shells with larger SAL, whereas males occupied shells with higher SAW, SCW, and TL.

Table 1. Mean and significance values (One-way ANOVA) of shell measurements - SAL (shell aperture length); SAW (shell aperture width); SCW (shell curve width); TL (total shell length); and hermit crab measurements - CSL (cephalothoracic shield length); CSW (cephalothoracic shield width) comparing the different sexes of hermit crab. Significant differences are indicated by: >0.05=*; >0.01=**. >0.001=***).

Morphometry	Male	Ovigerous Female	Intersex individual	Female	Significance
SAL	19.37 ± 3.58	19.74 ± 11.89	18.59 ± 3.41	17.7 ± 3.31	***
SAW	9.74 ± 2.44	8.7± 1.94	9.52 ± 2.48	8.78 ± 2.18	***
SCW	21 ± 4.41	19.86 ± 2.82	19.85 ± 3.74	18.84 ± 3.9	***
TL	32.98 ± 6.36	31.63 ± 4.14	31.89 ± 5	29.87 ± 5.57	***
CSL	5.85 ± 1.42	5.72 ± 1.09	5.76 ± 1.11	5.16 ± 1.07	***
CSW	5.05 ± 1.25	4.75 ± 0.87	4.9 ± 0.93	4.46 ± 0.89	***

CSL was higher during rainy season (F= 9.67; p= 0.00). On the other hand, there were no differences in all others shell measurements between seasons (CSW - F= 2.30; p= 0.13, SAL – F= 0.67; p= 0.41, SAW – F= 1.28; p= 0.25, SCW – F= 0.47; p= 0.49, TL – F= 1.40; p= 0.2.

Table 2. Mean and significance values (One-way ANOVA) of shell measurements - SAL (shell aperture length); SAW (shell aperture width); SCW (shell curve width); TL (total shell length); and hermit crab measurements - CSL (cephalothoracic shield length); CSW (cephalothoracic shield width) between local climatic seasons (dry x rainy) Significant differences are indicated by: >0.05=*; >0.01=**. >0.001=***).

Morphometry	Dry	Rainy	Significance
SAL	18.29 ± 5.58	18.57 ± 3.5	NS
SAW	9.02 ± 2.37	9.22 ± 2.25	NS
SCW	19.56 ± 3.99	19.77 ± 4.24	NS
TL	30.85 ± 5.67	31.37 ± 6.09	NS
CSL	5.31 ± 1.16	5.59 ± 1.3	***
CSW	4.63 ± 1.02	4.75 ± 1.09	NS

There were significant differences in hermit crab size between channels. They were larger in channel 1; CSL (F= 34.35; p= 0.00) and CSW (F= 21.16; p= 0.00). There were also significant differences in shell measurements - SAL (F= 4.09; p= 0.04) and TL (F= 15.13; p= 0.00), which were also higher in channel 1. Shell measurements such SAW and SCW did not show these differences; SAW (F= 1.56; p= 0.21) and SCW (F= 2.11; p= 0.14).

Table 3. Mean and significance values (One-way ANOVA) of shell measurements - SAL (shell aperture length); SAW (shell aperture width); SCW (shell curve width); TL (total shell length); and hermit crab measurements - CSL (cephalothoracic shield length); CSW (cephalothoracic shield width) between channels (C1 X C2). Significant differences are indicated by: >0.05=*; >0.01=**. >0.001=***).

Morphometry	Channel 1	Channel 2	Significance
SAL	18.82 ± 5.69	18.13 ± 3.54	***
SAW	9.25 ± 2.39	9.03 ± 2.25	NS
SCW	19.92 ± 3.89	19.47 ± 4.28	NS
TL	32.06 ± 5.5	30.37 ± 6.09	***
CSL	5.75 ± 1.34	5.22 ± 1.1	***
CSW	4.9 ± 1.17	4.54 ± 0.94	***

There was a significant predominance of non-ovigerous females over males both in seasons [x^2= 86.80; p= 0.00] and channels [x^2= 79.70; p= 0.00]. Non-ovigerous females showed a significantly higher ratio during dry season (2.8:1) and in channel 1 (1.8:1) (Tab. 4).

Table 4. Percentage of hermit crab sexes relative to seasons (dry x rainy) and channels (Channel 1 x Channel 2) studied.

Seasons	Ovigerous Females	Females	Males	Intersex individuals
Rainy	45 – 11.94%	173 – 45.89%	157 – 41.64%	2 – 0.53%
Dry	7 – 1.98%	229 – 65.06%	82 – 23.30%	34 – 9.66%
Channels	**Ovigerous Females**	**Females**	**Males**	**Intersex individuals**
C1	51 – 15.84%	158 – 49.07%	88 – 27.33%	25 – 7.76%
C2	1 – 0.25%	244 – 59.95%	151 – 37.10%	11 – 2.70%

Discussion

There was higher abundance of *C. vittatus* during rainy season. The highest abundance during rainy season is related to low salinities in the estuary (MCLAUGHLIN; MURRAY, 1990) unlike dry season, as pagurans are exposed to thermal stress and desiccation during the latter period (BERTNESS, 1982). Similar effects have also been recorded in studies in other Brazilian regions, e.g. the state of *Ceará* (VIANA et al., 2005).

Males had larger measurements, thus emphasizing sexual dimorphism in size, which is common in hermit crabs (MANTELATTO et al., 2007; AYRES-PERES et al., 2008). Higher size classes are comprised of males in *C. vittatus* populations, both in the Northern (LOWERY; NELSON, 1988) and the Southern Hemispheres (TURRA; LEITE, 2000). Males had a larger size class, as they do not need to spend energy for egg production, using it for their growth. Moreover, the larger size of males indicates an advantage in the competition for females and shells (HARTNOLL; ABELE, 1982).

Although males are larger, there was predominance of females on *Ajuruteua* beach. A similar pattern occurred in the studies by Negreiros-Fransozo et al. (1991) and Turra e Leite (2000). This sex ratio away from 1:1 is common among crustaceans and might be caused by sexual reversal, differential migration, differential mortality, and different growth rates (WENNER, 1972). According to Fotheringham (1975), a sex ratio skewed towards males indicates differential migration of sexes**.** Therefore, females would remain on sandbanks until mating, and after they had been fertilized, they would migrate to a more stable area with probably higher salinity, as this seems to be an important factor for the development of larvae (FOTHERINGHAM; BAGNALL, 1976). The higher abundance of females in C1 might be attributed to the fact that ovigerous females settle at sites that are favorable for reproduction, which are more frequently flooded as *C. vittatus* is not a terrestrial species (TURRA, 2007).

Ajuruteua beach has mean semi-diurnal tides of 4 m and areas closer to the beach are flooded for about 2 h, with flood velocity around 0.87m/s (SOUZA-FILHO et al., 2009). Moreover, C1 does not become completely dry, increasing the potential for egg and larval transport to coastal waters.

Low frequency of intersex individuals is one of the characteristics of *C. vittatus* (TURRA; LEITE, 2000) populations and their role in hermit crab species is difficult to interpret (GUSEV; ZABOTIN, 2007). Intersex individuals used to be considered functional males due to their ability to fertilize females (TURRA, 2004). However, the discovery of egg-carrying intersex individuals showed that they could also be functional females (TURRA, 2007).

C. vittatus population on *Ajuruteua* beach predominantly occupied *S. haemastoma* shells. A similar pattern was observed in the coast of *São Paulo* (NEGREIROS-FRANSOZO, et al., 1991). Shells of this species are frequent throughout the Brazilian coast (SANT'ANNA et al., 2006) and their characteristics make them suitable for occupation: large rounded openings and rounds and spacious internal area (ABRAMS, 1988). Moreover, they are resistant to predation and to the impact of waves; stronger tides might break more fragile shells from other species (SANT'ANNA et al., 2008). The largest *Stramonita* shells on *Ajuruteua* Beach are occupied mostly by males (also with larger morphometric measurements) and ovigerous females (possibly, for the protection of eggs). A similar pattern has already been described on a different sandy site in northeastern *Pará* state coast (*Marapanim*) for *C. symmetricus,* a different but common specie of hermit crab (RODRIGUES; MARTINELLI-LEMOS, 2016).

C. vittatus reproduction is seasonal and occurs between April-October in the Northern Hemisphere (LOWERY; NELSON, 1988), and October-July in *São Paulo* (TURRA; LEITE, 2000), months with more frequent rains. A higher occurrence of ovigerous females on *Ajuruteua* beach was observed during rainy season. Larval settlement during winter might benefit from the decreased saline stress caused by rains, with consequent higher freshwater flow in the rivers and lower abundance of predators and/or competitors (FOTHERINGHAM; BAGNALL, 1976).

Conclusion

Regardless of sex, hermit crabs preferred shells of the genus *Stramonita*. Males had the largest measures, followed by ovigerous females, which corroborates other studies. Hence, they occupied the largest shells. There appears to be little or no environmental influence among seasons on crab and shell measures or occupation patterns. To elucidate the influence of rainy and dry regional seasons over ecological and biological characteristics of hermit crabs and shells, we suggest long-term studies and greater coverage in the coastal zones of the Amazon coast.

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